NASA Technical Memorandum 100 461

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ABSTRACT

The vestibulo-ocular reflex (VOR) may be altered by weightlessness. Since this reflex plays a large role in visual stabilization, it was important to document any changes caused by space flight. This is a report of findings on STS-4 through 6 and is a part of a larger study of neurosensory adaptation done on STS-4 through 8. Voluntary horizontal head oscillations at 1/3 Hz with amplitude of 30° right and left of center were recorded by a potentiometer and compared to eye position recorded by electroculography under the following conditions: eyes open, head fixed, tracking horizontal targets switched 0°, 15° and 30° right and left (optokinetic reflex [OKR] and calibration); eyes open and fixed on static external target with head oscillation (visual vestibulo-ocular reflex (VVOR)); eyes closed but fixed in imagination on previous target with head oscillation, (vestibulo-ocular reflex, eyes closed (VOR EC)); eyes open and wearing opaque goggles with target fixed in imagination (vestibulo-ocular reflex, eyes shaded (VOR ES)); and eyes open and fixed on a head synchronized target with head oscillation (VOR suppression). No significant changes were found in voluntary head oscillation frequency or amplitude in those with (n=5), and without (n=3), space motion sickness (SMS), with phase of flight or test condition. Variations in head oscillation were too small to have produced detectable changes in test results. Four subjects with adequate data showed no significant change in VVOR gain/phase, VOR EC gain/phase or VOR suppression. There was a small but significant increase in VOR ES on MD-4 and similar increase in phase shift (eyes lead head) on MD-2 and 4 during VOR ES. There was no evidence for any change of clinical or operational significance. The validity of the above findings will be further tested when similar data from STS-7 and 8 (n=10) are available.

INTRODUCTION

A complex spatial reference system essential for interaction with the environment is constantly maintained in the human nervous system. It is referenced to the head, probably because two of the three major transducers are located there; i.e., eyes and vestibular organs. Input from the body (somatosensory) is the third major source of reference information. A large portion of this reference system is devoted to visual and ocular control and a major aspect of ocular control is dependent upon the vestibular system. While primary control of eye position is derived from vision itself (OptoKinetic Reflex [OKR]) both amplitude and frequency response of the visual tracking loop during head motion are improved by the inertial input from the semicircular canals with lesser input from the otolith organs. This Vestibulo-Ocular Reflex (VOR) operates in both vertical and horizontal planes and its characteristics may be measured by recording eye and head motions under controlled conditions.

There are both theoretical and operational reasons for study of the VOR in space flight. Effects of weightlessness, an environment unavailable on Earth, may provide additional insight into interaction of semicircular canals and gravity sensitive otolith organs and possibly other elements of the greater vestibular system. At the beginning of the study to be described it seemed possible or even likely that a disturbed VOR which upset visual imagery could be a cause or significant contributor to Space Motion Sickness (SMS)(1). Such a disturbance could arise from physical changes secondary to weightlessness; e.g., transient labyrinthine hydrops from the fluid shifts which are known to occur over roughly the same time period as SMS. For these reasons, study of the VOR was high on the list of things to be done when possible on Space Shuttle flights.

An operationally oriented Johnson Space Center (JSC) program to investigate neurological adaptation was begun on STS-4 (June 1982) and continued through STS-8 (August 1983)(2). Preflight, launch, on-orbit, entry and postflight Electro-Oculographic (EOG) studies were performed. Clinical results from this study have been reported(3), however, this is the first detailed report of quantitative results. This paper reports the results of studies of Visual Vestibulo-Ocular Reflex (VVOR), VOR with eyes open and vision blocked (designated ES) and with eyes closed (EC), and VOR suppression studies performed on STS-4 through 6 with 8 subjects using voluntary head oscillation as the stimulus (Table 1).

They are part of a larger series which included 10 additional subjects on flights 7 and 8 (1983)(2).

Prior to STS-4, EOG studies had not been done in space. An effective EOG system was part of Shuttle for the Operational Biomedical Monitoring System (OBS) designed and used for EKG monitoring had all the technical characteristics required, including provision for the necessary increase in gain for EOG work. A demonstration of recording of EOG on orbit using this system was made on STS-4 in which both crewmen made programmed head movements and the resulting eye movements were recorded via telemetry at JSC.

Following this demonstration an effort was implemented to perform standard clinical EOG protocol studies pre-, post-, and inflight on crewmembers with and without SMS. On STS-5 active unpaced head oscillation was used as a stimulus with head position determined by a flexible shaft

Table 1.— Summary of Studies

	Subject			
	1	2	3	4
STS-4#				
Preflight	L-16D	L-16D		
Flight 1	00:14:00	+		
Flight 2	02:06:13	02:06:02		
Flight 3	03:23:45	04:00:05		
STS-5@				
Preflight 1	—	L-35D		
Preflight 2	L-28D	L-28D		
Preflight 3	L-14D	L-14D		
Launch 1	00:00:12	—		
Launch 2	00:02:55	—		
Flight 1	00:22:42	00:23:11**		
Flight 2	02:21:43	02:21:37		
Entry 1	—	05:01:13 (.07g)		
Entry 2	—	05:01:36 (~0g)		
Entry 3	—	05:02:12 (1.0g)		
Postflight 1	R + 1H	R + 1H		
Postflight 2	R + 6D	R + 6D		
STS-6				
Preflight 1	L-70D	L-69D	—	—
Preflight 2	—	—	—	L-52D
Preflight 3	L-47D	—	L-47D	L-47D
Preflight 4	—	L-14D	—	—
Flight 1	01:11:00*	+	01:11:11*	01:11:21*
Flight 2	02:03:28	02:03:39	02:04:07	02:03:59
Flight 3	03:23:09	03:23:35	03:23:23	03:23:46
Postflight	R + 1H	—	R + 1H	R + 1H

Note: Flight times are Mission Elapsed Time (dd:hh:mm)
+ Subject had SMS, no data obtained
* Head position data lost
** Subject had just recovered from SMS
# EOG data only
@ Head position data from head pot. with flex. shaft.

coupled to a potentiometer and eye position recorded by EOG. It was recognized that the flex shaft coupling for head position was subject to translation induced error such that only relative gain measurements were planned. To eliminate this translation error, a pantograph mounting for the head position potentiometer was developed for STS-6. In addition, opaque eye goggles were added to allow eyes open studies in darkness. These procedures allowed study of VVOR, VOR (EC and ES), and VOR suppression pre-, in-, and postflight.

While STS-4 crewmen recorded eye motion only, crewmen on STS-5 and 6 measured VVOR and VOR gain and VOR suppression using voluntary head oscillation as the stimulus. Data from all flights show no significant change either in frequency or amplitude of head oscillation over the entire pre-, in-, and postflight period, or during the varying conditions of EO, EC, and ES. There were no significant differences between subjects with and without SMS. Four subjects with adequate data showed no change in VVOR and VOR EC gain. With VOR ES, significant changes in phase relation were found on flight days 2 and 4 with an increase in gain on day 4 only. VOR suppression was unchanged.

Related Studies

At least 4 related studies have subsequently been done in space(4,5,6,7). In November 1983, Benson(4) devised an *ad hoc* experiment on Spacelab 1 to study changes in horizontal and vertical VOR EC gain in 2 subjects with voluntary head oscillation at 1 Hz. The horizontal values obtained ranged from 0.4 to 0.69 inflight and 0.5 to 0.85 postflight with means of 0.6 inflight and 0.7 postflight. While the conclusion was that gain had not changed, it is tacitly assumed by many investigators that eyes closed EOG signals differ significantly from dark, eyes open values, which is the accepted means of measurement.

In 1984, Kornilova(5) studied the OKR onboard Salyut 7. Eye movements were recorded by EOG before and after head shaking; however, head movements were not recorded and no data on VOR reflex were obtained.

Watt(6) studied VOR gain in two subjects on Space Shuttle mission STS-41G (1984) by two methods. The first used voluntary head oscillations of increasing frequency until oscillopsia occurred. No changes were observed between pre-, in-, and postflight periods. The second was a non-standard test of VOR gain in which static positions of head and eyes were measured after eyes open and eyes closed head turns. All gains appeared to be 1.0 and were unchanged inflight.

In 1985, Viéville(7) studied VVOR, VOR ES and VOR suppression of 2 subjects on STS-51G. The methods used were in principle similar to ours. They assumed a mean VOR gain of 1.0 preflight and found gains of 0.7, 0.75, and 0.85 on Mission Day (MD) 1, 4, and 7, respectively, with no change in VOR suppression inflight or postflight.

PROCEDURES

Subjects were all astronauts with no known or detectable vestibular or ocular defects. In each mission one subject was trained to perform the equipment setup and test per checklist, including the preflight baselines. On STS-6 an onboard physician astronaut performed the tests. All crewmen on STS-4 and STS-6 and 2 mission specialists on STS-5 participated.

EOG Recording. EOG recording methodology was the same on all flights. Commercial, disposable Ag-AgCl 1 cm diameter electrodes were placed at the outer canthus of each eye with a ground electrode on the mid forehead. Amplifier gain was ~1800x with frequency response of 0.05 to 100 Hz. Phase shift of amplifiers used was carefully measured (Table II-1). The signal was digitized at a rate of 400 Hz with a resolution of 256 bits, digitally recorded/transmitted to Earth where it was again recorded. The signals were also demodulated and transcribed by a Brush ink writing recorder of D.C. to 60 Hz response and 100mm recording width per channel. This system met or exceeded all technical standards for clinical EOG recording(8). Overall system noise limited resolution to approximately two degrees. Dark adaptation was not done, but the dark time (EC and ES) was limited to 15 secs typically and 30 secs maximum.

Targets. On STS-4, EOG calibration was done by having the subject look from one well-defined corner of the instrument panel to another with the head stationary at a known distance from the panel providing visual angles of 12° and 24°. Light emitting diodes (LEDs) were fixed in a horizontal plane at known distances at right and left visual angles of 0°, 10°, and 20° on STS-5, and 0°, 15°, and 30° on STS-6. They were switched at a nominal rate of 1.0 sec^{-1} in a fixed sequence. LED envelopes were of red, clear plastic, 4.5x7 mm, with light emitter areas less than 1 mm diameter.

The head synchronized target for VOR suppression consisted of a very light, rigid metal boom projecting 42 cm from the forehead support with a blackened 7 cm long steel wire supporting a 5 mm white sphere at eye level. This assembly was rigidly coupled to a closely fitting Spandex Cap (Fig. 1).

The Space Shuttle pilot's seat and restraint harness were used to maintain subject position on STS-4 and 6 with calibration lights attached to the instrument panel eyelid on

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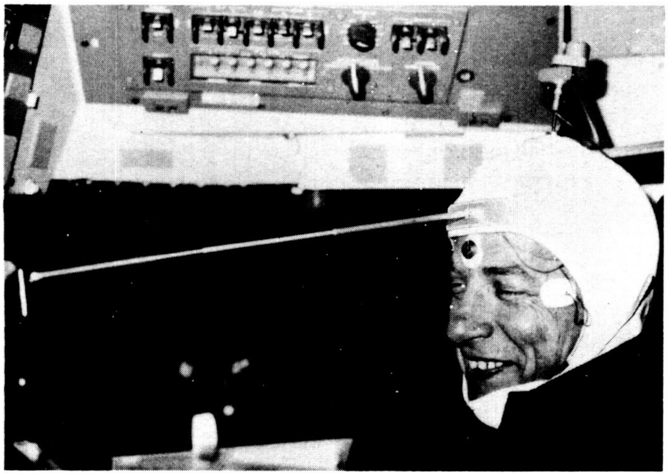


Fig. 1.— STS-6 crewman preparing for VOR suppression test with head synchronized target extended. Pantograph-mounted head position potentiometer may be seen attached to cap.

STS-6. On STS-5 subjects were temporarily secured to the middeck floor with calibration lights secured directly above on the overhead structure. All geometric values pertinent to the study were routinely measured and recorded, including the distance from eye to center-of-head rotation.

Head Position. Head position was not recorded on STS-4. The brief time available for construction of equipment for STS-5 required the use of a potentiometer coupled to a fixed structure by a flexible reference shaft. Such a reference arrangement produces angular errors with significant head translation. This source of error was eliminated on STS-6 by a pantograph mounting. This pantograph also drove the potentiometer at twice head angle limiting maximum error to $\pm 0.7°$ over its range of $180°$. The potentiometer and the digital transmission system were calibrated by rotating them through their full range and recording the maximum deflection. Zero position was taken as the head angle at zero angle target fixation. A small dead band near $360°$ was accounted for.

On STS-5 and 6, electronics and batteries for power were placed in a single small aluminum box with all functions controlled by a single multi-position switch (II-2 and II-3). This box could be clipped on and off a standard mounting bar on the seats. Operation was standardized for crewmen by a checklist.

Protocol. On STS-5, the procedure for VOR studies consisted of EOG calibration as described (Fig. 2), followed by 5 to 10 cycles of voluntary unpaced, eyes open, head oscillations at a nominal period of 3 sec and peak amplitude of $30°$ right and left of mid-position with eyes fixed on the center calibration target (VVOR) (Fig. 3). This was followed by identical sequences of head oscillation with eyes closed and the same target fixed in imagination (VOR EC) (Fig. 4) and with eyes open and fixed on the head-synchronized target (VOR suppression) (Fig. 5). On STS-6, a pair of light tight goggles was worn for an additional sequence of head oscillations with the center calibration target fixed in imagination (VOR ES). Instructions were carefully given and reinforced on fixation of this imaginary target until characteristic large, unbroken EOG signals were consistently reproduced. A record of all medication taken was maintained.

During STS-5 launch, subject 1 (Fig.6) was seated on the middeck with the calibration lights mounted on the lockers directly ahead. Calibration, eyes open and eyes closed head oscillation sequences were performed and recorded. On entry, subject 2 performed the same procedure. On STS-6, a head-mounted gyro and EOG signals were recorded with a modified Holter EKG recorder during launch and entry. Results from this recorder are not reported here.

Postflight, the equipment used onboard was moved to the clinical examination area and arranged in a configuration equivalent to that inflight. Graphic records were obtained from STS-5 and 6 subjects within 2 hours after landing.

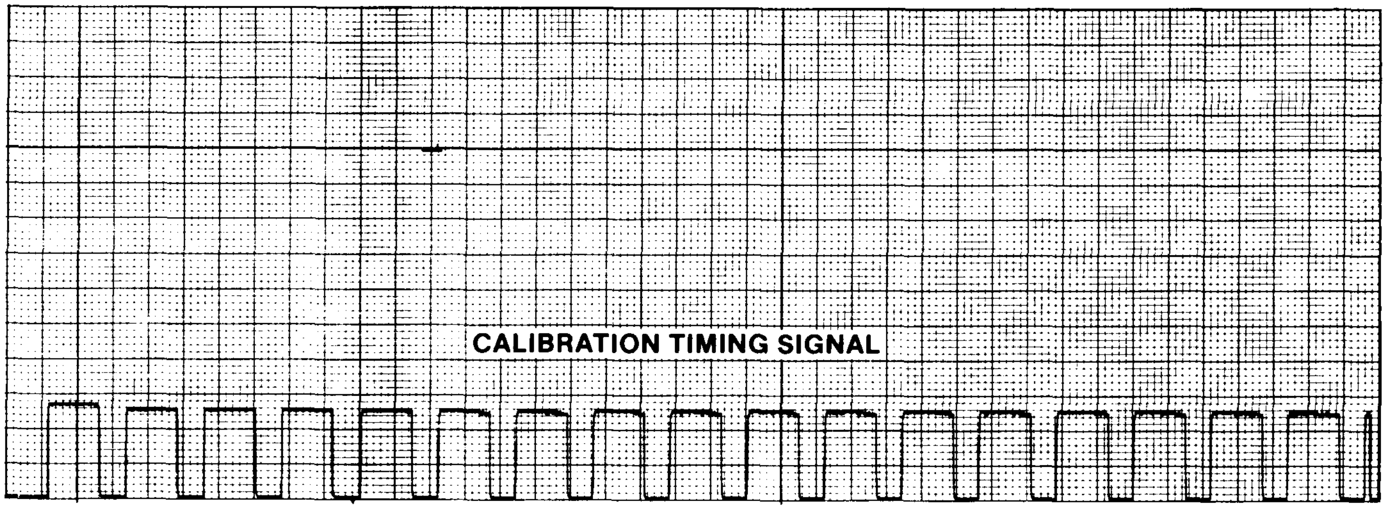
Data reduction and analysis

It was not possible to save the inflight digital data; hence, only graphic records were available. A bit pad with computer and disk storage were obtained and a program written to reduce, store and calculate VVOR and VOR parameters. While most of the data was initially processed with this, it proved to be simpler to reduce all data a second time manually and process them by hand-held computer.

EOG Data. The target distance was measured on each run and visual angles calculated. A mean of values from the extreme right and left target angles was used since they approximated the eye angles under study. EOG data from head oscillation were corrected for geometric differences between center-of-eye and center-of-head rotation by the method of Mansson(9) and for phase and gain characteristics of the amplifiers used.

Head Position Data. Appropriate scale factors were obtained from the rotation of the head potentiometer through its full range prior to each study and allowance made for the small known dead band. Head movements were scaled accordingly. Zero position was taken as that with eyes fixed on the center calibration target.

The data obtained were used to calculate the following voluntary head oscillation parameters: Frequency was measured from head signals except in the case of STS-4 and MD-1 of STS-6 when undistorted EOG signals were used in



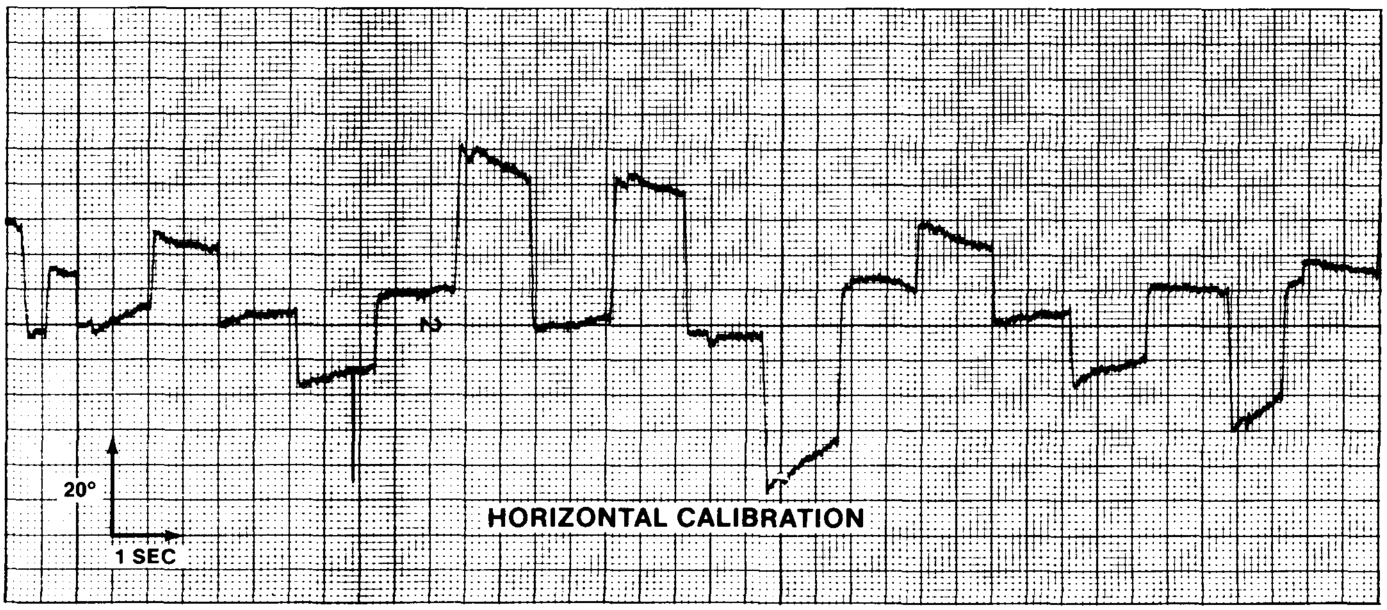


Fig. 2.— Inflight EOG calibration signal. Target lights were switched on downstroke of timing signal.

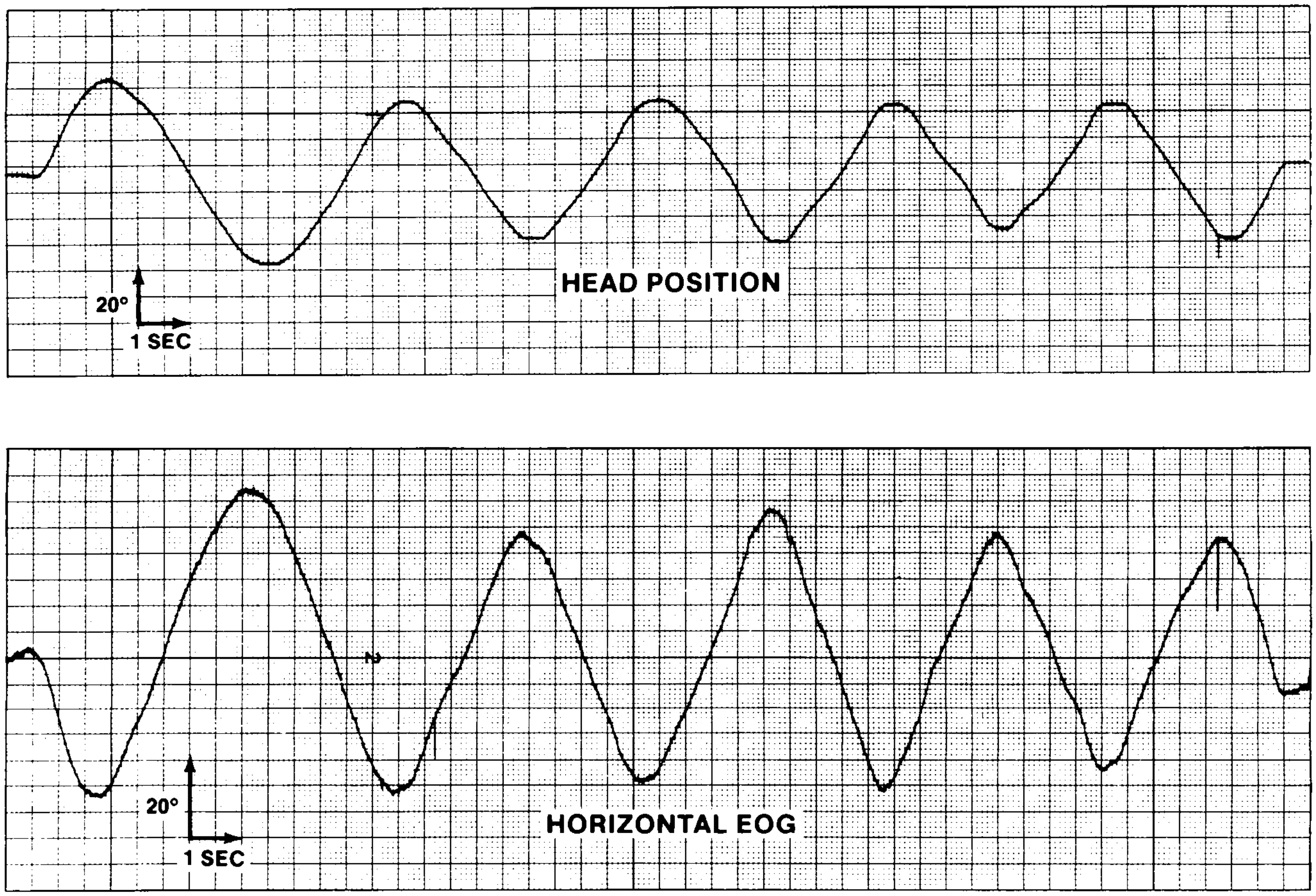


Fig. 3.— Head and eye position signals with eyes open and fixed on a stationary target during head oscillation inflight (VVOR).

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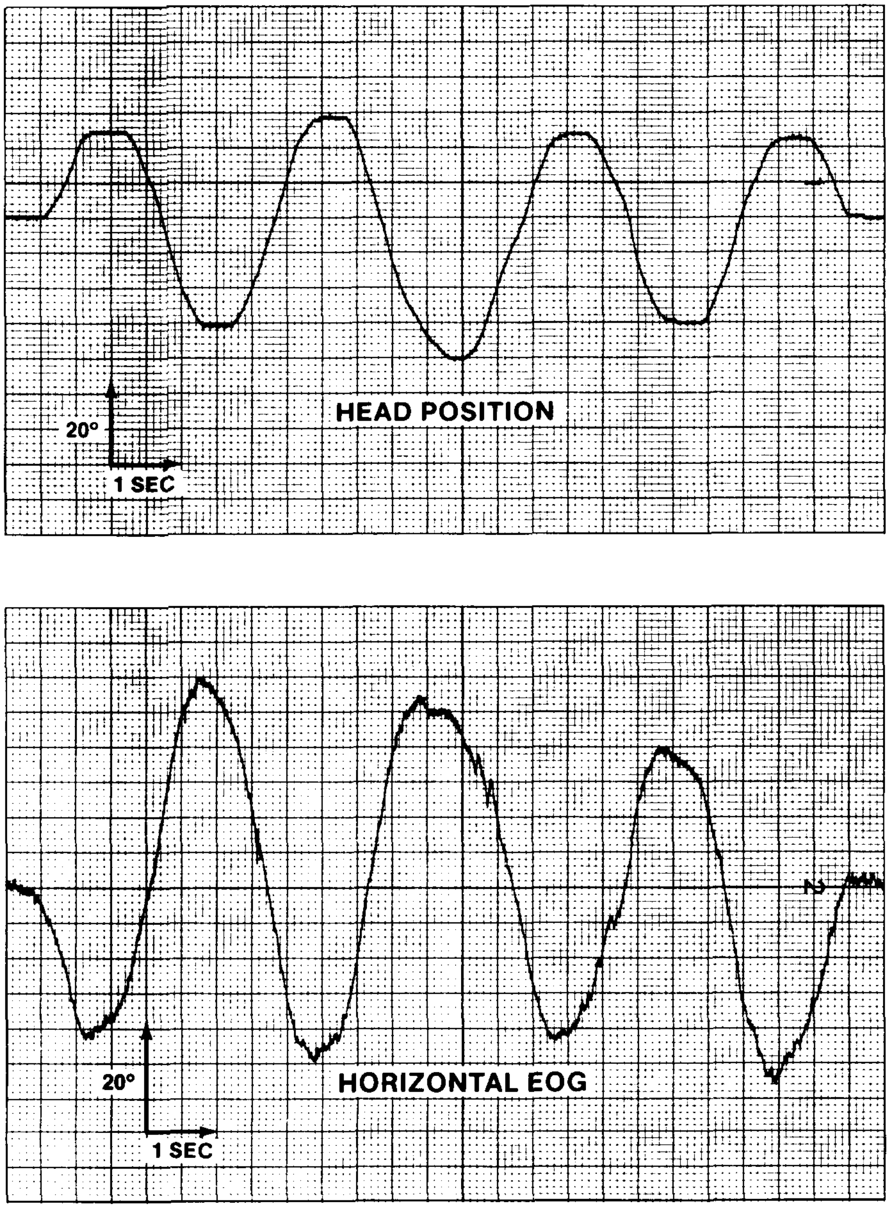

Fig. 4.— Head and eye position signals recorded inflight during head oscillation with eyes closed (VOR EC).

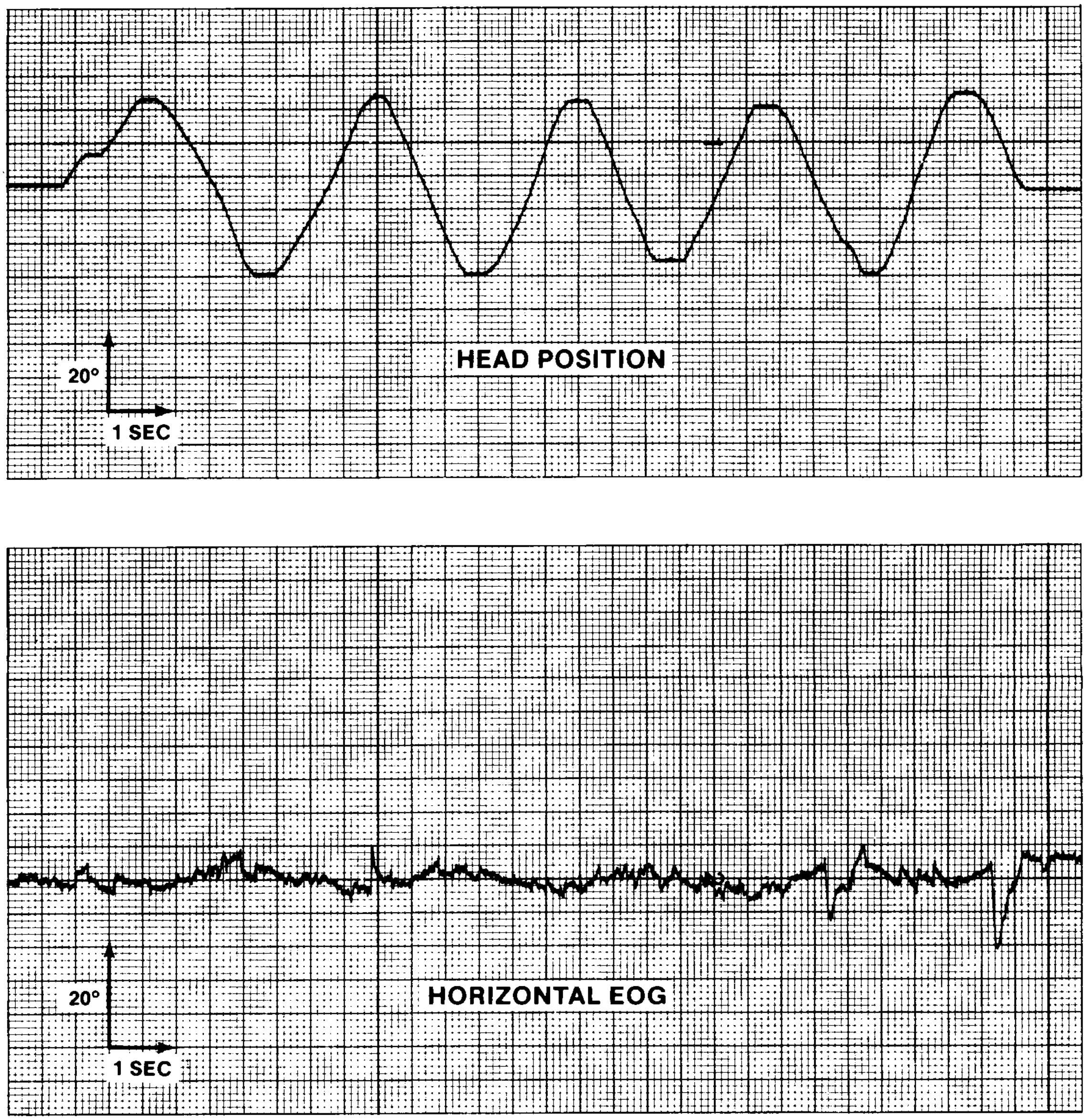

Fig. 5.— Head and eye position signals recorded inflight during head oscillation with eyes open and fixed on a head synchronized target (VOR suppression).

the absence of head position data. The period required for two crossings of the baseline by one cycle was converted to frequency and the mean of the frequency of all head turns in a sequence used. Recorder time accuracy was on the order of 1 percent and the record was continuously calibrated by crystal controlled time markers. Phase shift was measured by determining the time difference between the peaks of head and eye signals and the angular difference computed by comparisons to the time period of the head signal. Head and eye amplitudes were calculated at the maximum and minimum of each cycle using the eye and head position calibration factors. The mean and S.D. of amplitudes of all cycles in a procedure were used. A qualitative description of the head signal wave shape; e.g., sinusoidal, triangular, etc., was made of each sequence and the number of cycles counted for that sequence.

VVOR and VOR Gain. Gains were determined by dividing peak amplitudes of eye oscillation by corresponding head oscillation amplitudes. In the majority of cases, eyes closed or shaded EOG signals were continuous approximations of sine waves. In a few cases that were segmented, cumulative eye position was manually reconstructed by summing the slow phases of nystagmus and the peak amplitude of the resulting wave determined (Figure 7)(10).

VOR Suppression. In only one sequence was a waveform visible; i.e., suppression of the VOR was almost complete. Rather than attempt to determine gain, we feel it is more appropriate to analyze nystagmoid movements from baseline as errors or slips induced by the VOR and corrected by the OKR. To calculate the mean error of head synchronized target tracking, the number and amplitude of all detectable slips occurring during 2 head cycles were measured and the mean determined.

Statistics. Statistical analysis was performed using the General Linear Models procedure in the Statistical Analysis System. Repeated measures analysis of variance tests allowed comparisons among experimental conditions, as well as between preflight and inflight measurements. Additional statistical comparisons were made using MANOVA test criteria and analysis of variance of contrast variables (11). This also allowed comparisons to be made between the two subpopulations of subjects; i.e., those susceptible to SMS and those not susceptible.

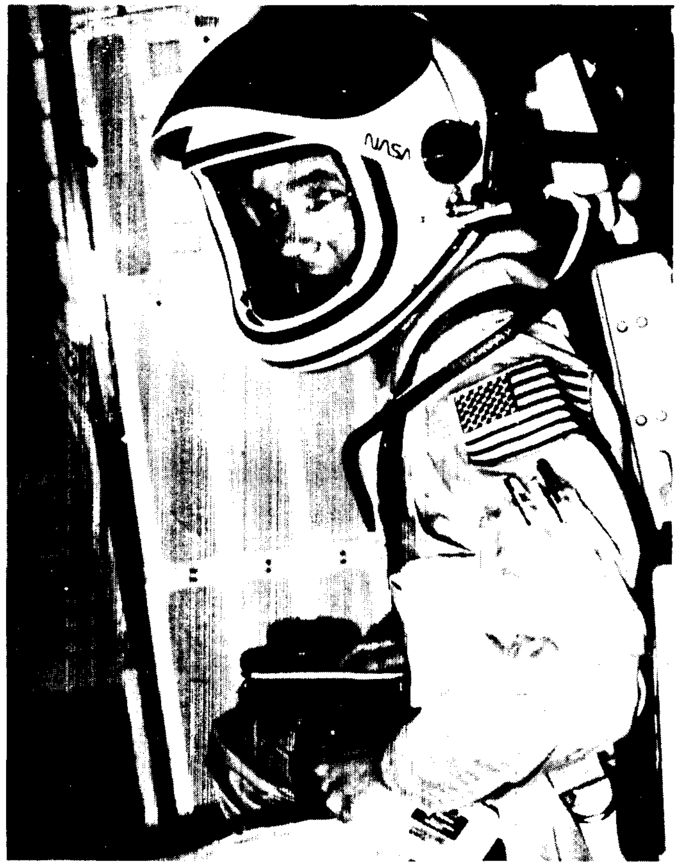

Fig. 6.— STS-5 crewman in launch position with EOG electrodes and head potentiometer in place. The photograph has been rotated from the vertical launch position to horizontal position here for clarity.

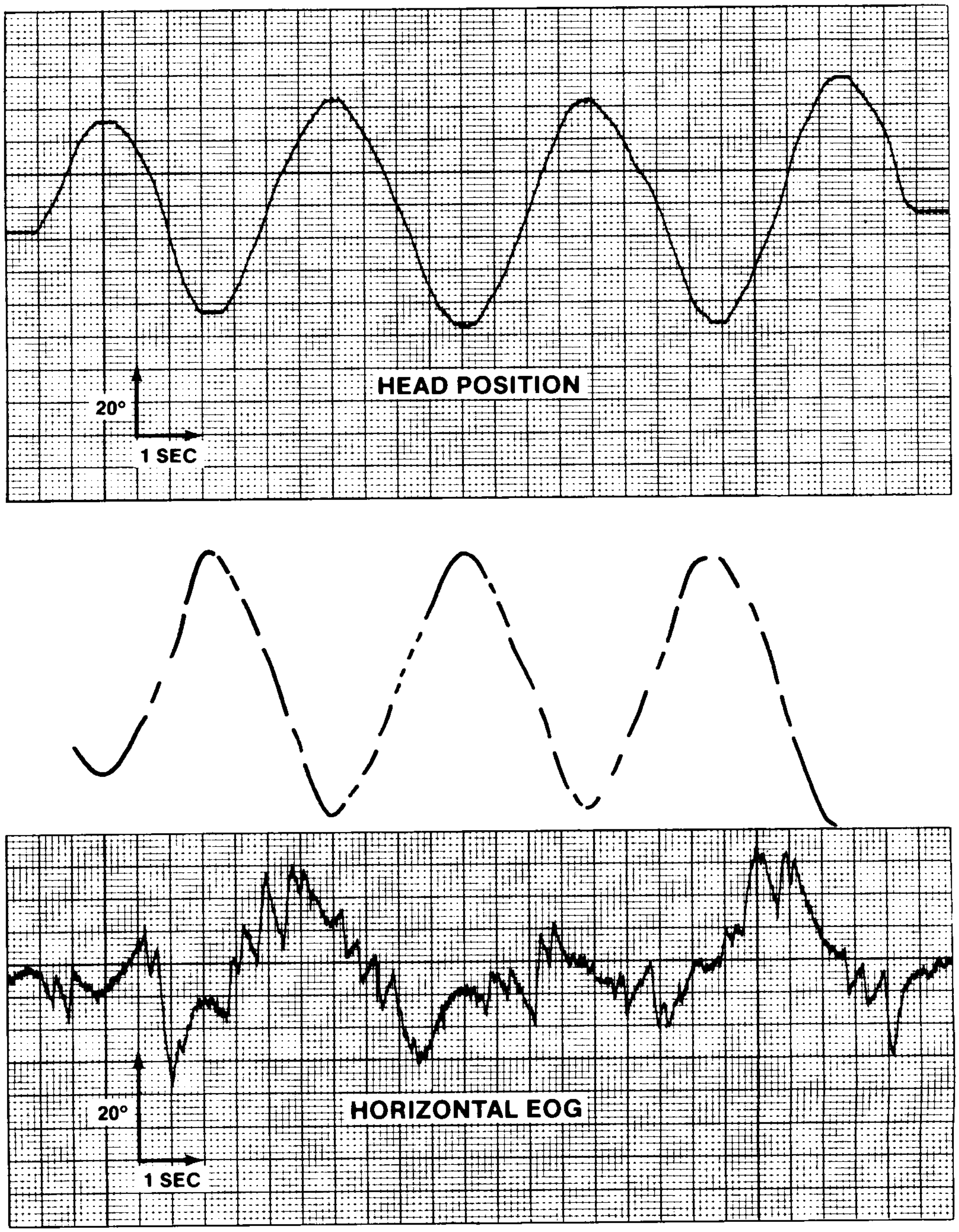

Fig. 7.— Segmented EOG recorded inflight during head oscillation with vision occluded. Cumulative eye position tracing was reconstructed by summing slow phases of nystagmoid movements.

RESULTS

A summary of the records obtained is given in Table 1. A total of 43 records was obtained from 8 subjects, of which 14 were preflight, 22 inflight, and 7 postflight. Three subjects had SMS on MD 1, but no records were obtained during their period of illness. Head position data on STS-5 were considered unreliable because of potentiometer coupling problems with the flexible shaft. Head position data were not transmitted on the MD1 recording session from crewmen on STS-6. No cause for this could be found and all equipment subsequently worked well. A single record from 1 subject on STS-5 on MD4 showed large eye oscillation signals, but it was concluded this was motion artefact.

Head Oscillation Parameters. Mean frequency of oscillation for all subjects under all conditions was 0.278 Hz with individual-to-individual range of 0.244 to 0.367 Hz versus the requested 0.333 Hz (I-1 — I-4B). Oscillation frequency for the test conditions versus flight days and for the individuals who did and did not experience SMS versus flight days are plotted in Figure 8A and B. Changes in frequency of oscillation did not significantly vary with test condition or date, and no significant differences were found between the two subpopulations.

Peak-to-peak eye amplitudes as recorded by EOG are summarized in the Appendix (I-5 to I-6). Mean peak amplitude and maximum angular velocity of head oscillation for those who did and did not experience SMS are plotted in Figure 9A and B as a function of flight days. Neither amplitude nor velocity changes reached significance as regards population or time.

Right vs. left oscillation amplitude preponderance was variable and no pattern could be found. In the same way no pattern or consistent change in wave shape could be determined, but there appeared to be a tendency for the head motion wave form to become trapezoidal inflight; i.e., with a delay between linear motion in the opposite direction (I-9A — I-10B). Sinusoidal motion seemed more prevalent postflight. Number of cycles of oscillation; i.e., head turns, for all subjects and test conditions are given in I-8. Variations with time, test conditions or susceptibility to SMS were not significant. The larger numbers preflight probably reflect simultaneous coaching with training during the preflight data gathering.

Reflex gains and phase shifts. Summaries of these are given in the Appendix (I-11A — I-14B) but analysis was limited to data from STS-6. Means and S.D. of gains and phase shifts for VVOR, VOR EC, and VOR ES are shown in Figures 10A and B. Postflight, one subject had a very high VVOR gain (1.22), and this accounts for the high mean. No technical reason could be found to remove this point although inattention is a possible explanation. Only changes in VOR ES (eyes open but dark) reached significance with an increase in gain on MD4 and an increase in phase shift (eyes leading head) on MD2 and MD4.

VOR Suppression. Table 2 lists the mean number of 'slips' per two head cycles and mean amplitude of the 'slips.' Changes in these values from preflight means did not reach significance. VOR suppression was virtually complete during all phases of flight, with gain remaining essentially zero.

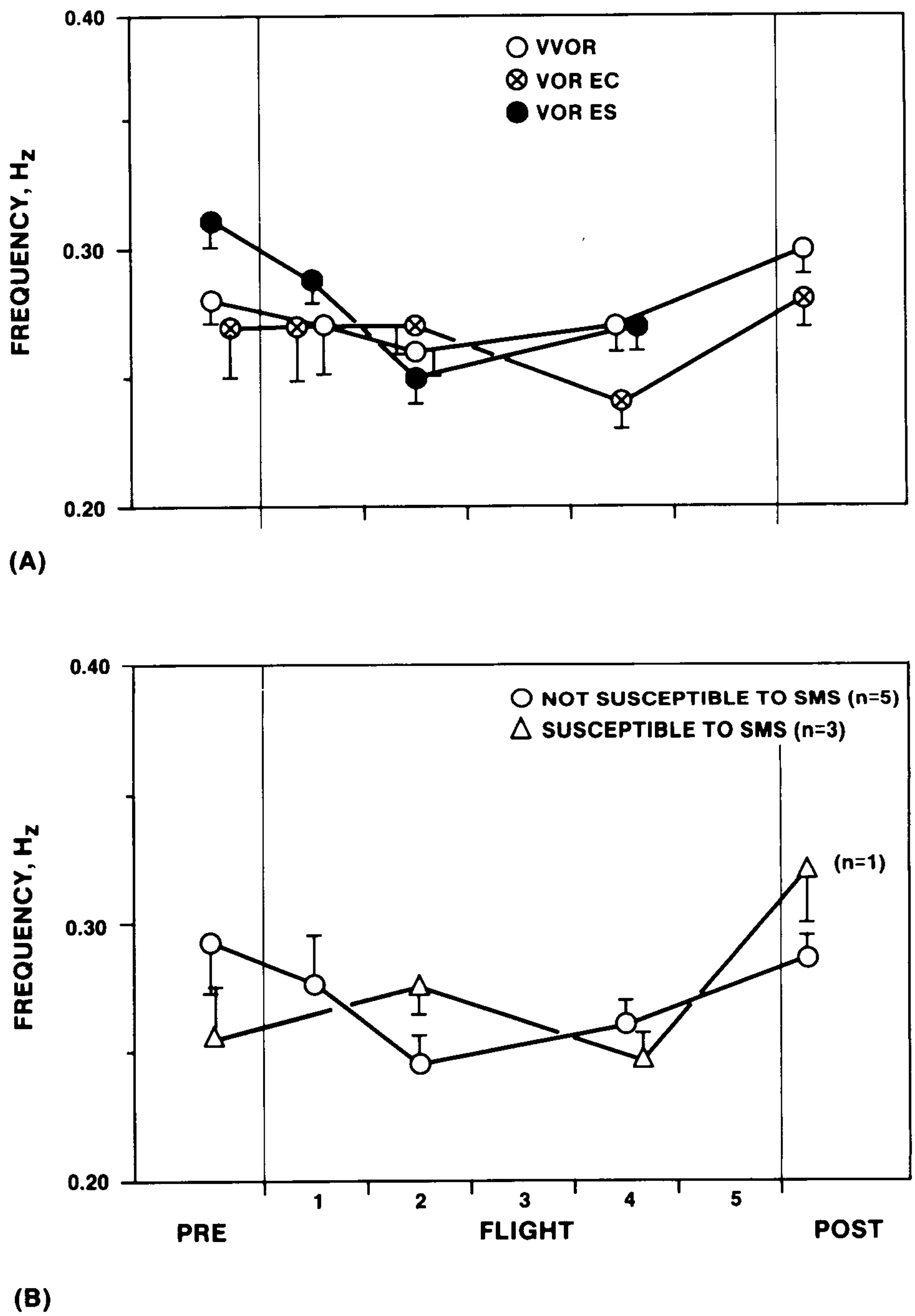

Fig. 8.— (A) Mean head oscillation frequency of 8 subjects during three test conditions as a function of flight time. Changes did not reach significance ($p \geq 0.05$). (B) Mean head oscillation frequency data pooled for the three test conditions, and subjects divided into subpopulations of susceptible or not susceptible to SMS. Changes did not reach significance ($p \geq 0.05$).

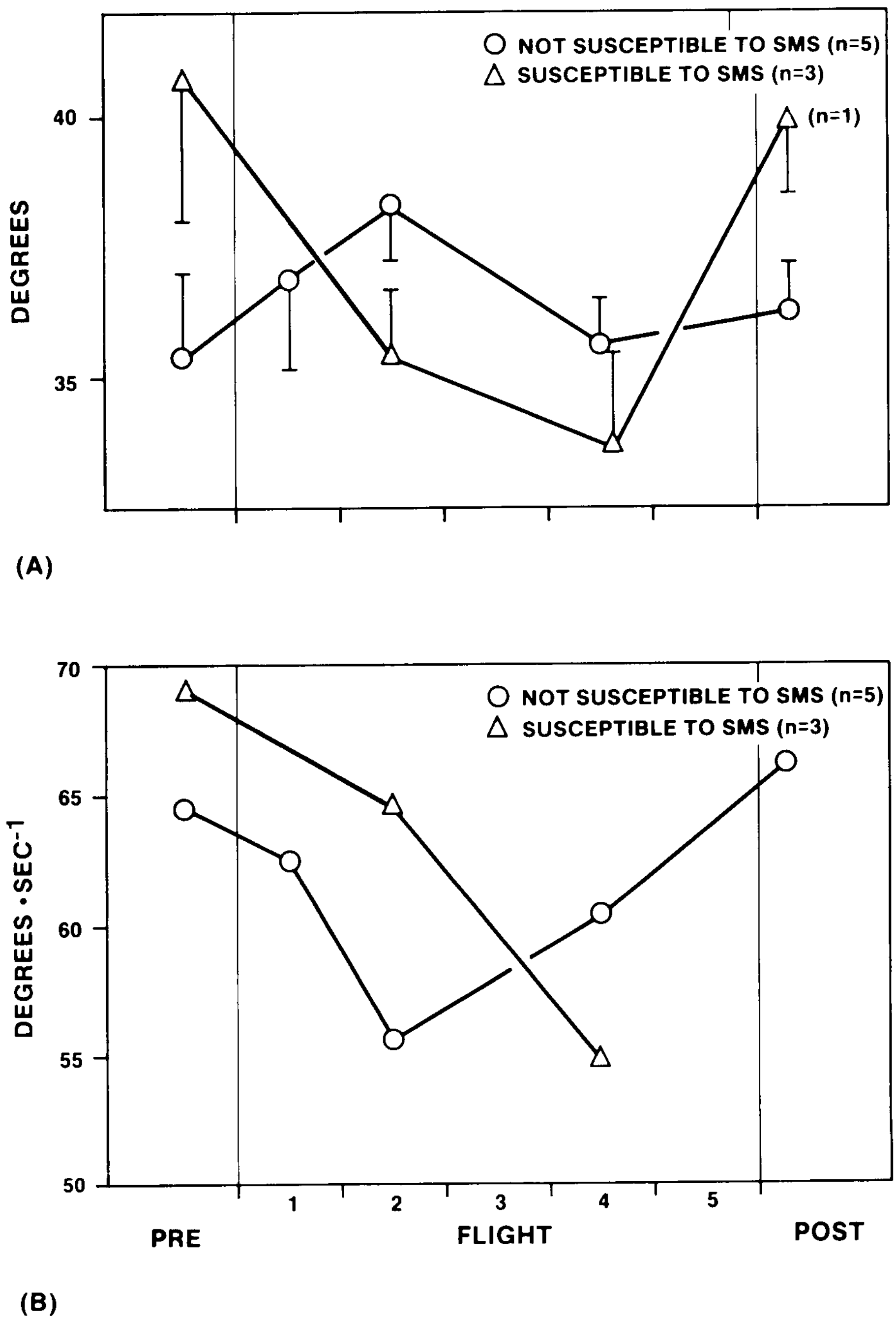

Fig. 9.— Mean peak amplitude (A) and maximum angular velocity (B) of head oscillation for those subjects susceptible and not susceptible to SMS as a function of flight time. Changes did not reach significance (p $\geq$0.05).

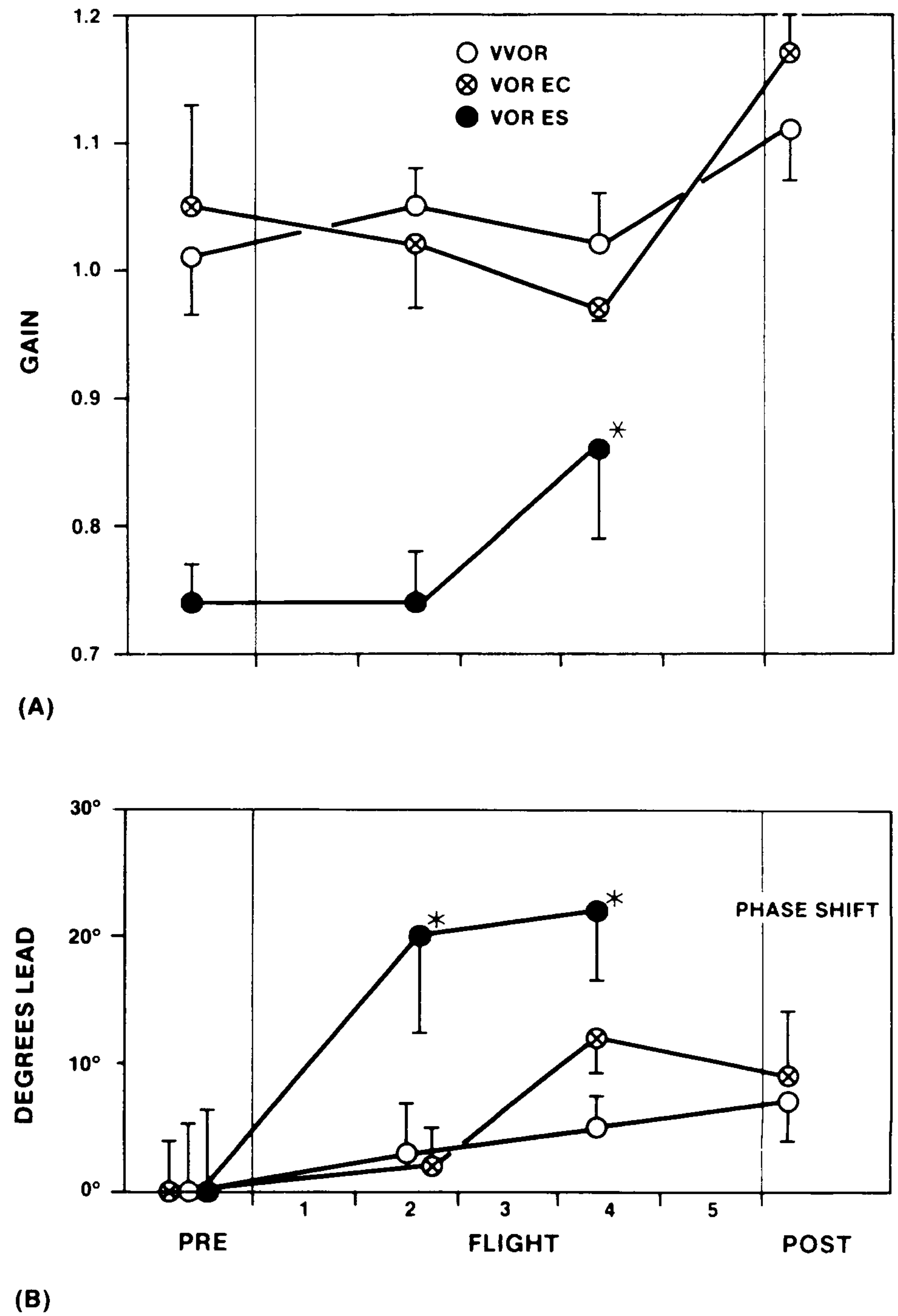

Fig. 10.— Reflex gain (A) and phase shift (B) during three test conditions as a function of flight time from 4 subjects (STS-6). Phase shift denotes eyes leading the head. (*) denotes significant difference from preflight means ($p \leq 0.05$).

Table 2.— VOR Suppression STS-5 and 6

Subject	Preflight	MD2	MD4	Postflight
STS-5 MS1 - n	16.5	9.0	10.0	11.0
ampl (°)	2.6	2.0	1.7	1.4
STS-5 MS2 - n	10.3		—	3.2
ampl (°)	4.3		–	2.5
STS-6 CDR - n	4.0	7.0	6.0	8.0
ampl (°)	1.8	2.6	1.7	1.7
STS-6 PLT - n	6.5	2.0	13.0	—
ampl (°)	4.9	3.2	4.1	–
STS-6 MS1 - n	10.0	7.0	3.0	19.0
ampl (°)	2.5	3.4	3.5	1.3
STS-6 MS2 - n	5.0	5.0	6.0	6.0
ampl (°)	3.7	4.8	6.1	3.0
Mean ± S.D. - n	8.7 ± 4.6	6.0 ± 2.6	7.6 ± 3.9	9.4 ± 6.1
ampl (°)	3.3 ± 1.2	3.2 ± 1.0	3.4 ± 1.8	2.0 ± 0.7

n = number of nystagmoid errors or slips per 2-head cycles
ampl (°) = mean of maximum amplitudes of slips (in degrees)

DISCUSSION

Voluntary head oscillation was used as the stimulus for the reflex studies and must be examined for effects of its variability on the results. Since effects of angular head motion also reach consciousness and have been suspected by some of being implicated in SMS(12), changes in this voluntary task were examined in this regard as well.

All three subjects with SMS elected not to participate in this experiment when symptoms were present (MD1). While this might be taken as evidence that angular head oscillation was provocative, subjects with SMS on subsequent flights participated in this protocol without difficulty. During SMS one avoids any task not considered mission essential(2) and this, plus psychological reasons associated with the situation, more likely account for the avoidance.

Other effects of head oscillation, either in individuals who had SMS and were recovered or in unaffected individuals, might be indicated by changes in some parameter of head oscillation; i.e., head amplitude, frequency or number of cycles of oscillation might be reduced. Frequency, amplitude, maximum velocity, number of head turns, and waveform were all statistically analyzed for changes between individuals who had, versus those who did not have SMS and as a function of mission phase. None of these reached significance. Trends which occurred inflight appeared to do so later rather than the first day or two when SMS occurs. Amplitude of head oscillation tended to increase in those not affected and decrease in those affected.

Preflight mean frequency and maximum velocity of oscillation tended to be greater in those affected by SMS. The question of whether any of these quantities become significant with a larger population may be answered when more data are available.

While changes in head oscillation did not reach significance, sensitivity of the various parameters in the reflex studies must also be examined to determine if they could be significantly affected by changes in stimulus values. It has been demonstrated that the VOR can be affected by the subject's mental activity(12, 13, 14, 15, 16, 17, 18, 19) and by stimulus intensity and frequency(20). It is also tacitly assumed by many researchers, including ourselves, that there is a large and variable difference between eyes closed VOR and dark, eyes open VOR.

Oscillation frequency was chosen to be in the range where gain changes are virtually independent of frequency (0.2 to 0.5 Hz)(16,20). Based on Wall's(20) data, the changes found in stimulus amplitude at the frequency chosen should have produced a maximum gain change of ~2% and negligible phase change.

Our VVOR gain data fell within limits usually obtained for this measurement in labs on Earth. While it is theoretically accepted that this gain must be exactly 1.00 or very close to it, in practice this is seldom the case. Data from three studies(15, 16, 20) using voluntary head oscillation showed mean gains of 0.99 to 1.005 but with S.D.s of 0.03, 0.1 and 0.15. Our pre-and inflight data fell within this range. Postflight means and S.D. were elevated by the values of one subject. While the changes did not reach significance, the suspicion of an elevated VVOR gain postflight is raised by an increased VOR EC value. Unfortunately, dark, eyes open (VOR ES) postflight data are not available. These data do not indicate visual disturbance inflight secondary to altered vestibular control of oculomotor function or any other cause.

We place little emphasis on eyes closed VOR data since they have such large variations on Earth, and our findings differ from the results of subsequent inflight investigations. Benson's(4) inflight values (n=2) from eyes closed VOR head oscillation at 1 Hz ranged from 0.4 to 0.69 (mean ~0.53) inflight and 0.5 to 0.85 (mean ~0.6) postflight.

These are considerably lower than our values of approximately 1.0. The difference could result from the large individual variation during eyes closed testing, or from a difference in fixing the target in imagination.

Our preflight VOR ES gain data (mean 0.74) were consistent with two of three investigations using voluntary head oscillation as the stimulus, and somewhat lower than values commonly reported with passive rotation. However, they were well within the range of variation of the majority of 1-g studies(14,17,18,20,21). Our inflight VOR ES gains also differed considerably from Watt's(6) values (n=2) of 1.0, but the techniques differed. Viéville's(7) VOR ES data from one subject with head oscillation at 0.25 Hz were ~0.7 on MD1 and rose to ~0.75 and ~0.9 on MD4 and 7, respectively. This is in contrast to our values which were unchanged from preflight on MD2 (0.74) and rose significantly to 0.86 by MD4. None of the other inflight investigators reported on eye head phase relations.

We found VOR suppression to be virtually complete preflight with gain essentially zero, and remaining so inflight and postflight. Laboratory studies on Earth with active and passive head oscillation with a head synchronized target show gains ranging from 0.07 to 0.32(12,13,14,15,16,17,18). Viéville's(7) pre-, in-, and postflight values were ~0.1. A different analysis was used here. It is not clear from their reports whether the other investigators used eye velocity waveform reconstructed from slow phase nystagmus or used the maximum slow phase velocity for a single point determination. In nearly all of our records there were only a limited number of nystagmoid movements from baseline. There were so few slips that it would have been impossible to reconstruct a VOR sinusoid. Instead we elected to characterize these nystagmoid slips as errors quantitated by their mean number and amplitude per 2 head cycles. These values did not change significantly with flight in any subject. It is possible that in this population of high performance jet pilots such suppression is more fully developed. In any event there was no indication of altered VOR or vestibular function affecting the normal OKR, as would be the case in labyrinthine hydrops.

CONCLUSIONS

VOR and associated studies of value can be done in operational space flight. Voluntary head oscillation without pacing cues can provide a reproducible stimulus to be substituted for passive oscillation in many areas. Susceptibility or non-susceptibility to SMS did not significantly affect voluntary head oscillation parameters.

Since neither VVOR nor VOR suppression was affected by flight it is difficult to ascribe any significant role to disordered vestibulo-ocular reflexes. This conclusion is also supported by similar data in Viéville's subject and by Watt's failure to find any change in oscillopsia induced by rapid head shaking.

The question of gain and phase changes in VOR remains open, for data from the few subjects reported here at a single frequency cannot be considered definitive. The three other inflight studies combined have an equal number of subjects, but three different methodologies were used and there is not agreement in the data. If data from this study are correct, then some form of relatively slow adaptation which produces small gain and phase changes in VOR ES in weightlessness might be inferred. This assumes that the cervico-ocular reflex remains unchanged. Data from STS-7 and 8 is being evaluated and may help clarify this question.

Implications of this study include: There is no measured evidence for concern over disordered oculomotor activity secondary to vestibular disturbance inflight. Active head oscillation can be used in many VOR and similar studies.

Useful data can be obtained from operational flights and flight crews.

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APPENDIX I — DATA SUMMARIES

This section is added to present all unprocessed data for others to use as they see fit.

Data — The following conventions were used:

EO is with eyes open and vision focused on a surround fixed target; e. g., the center LED which was lighted.

EC is with eyes closed, but focused in imagination on the above target.

ES is with eyes open, but vision occluded by light excluding goggles. The same target is fixed in imagination.

HT is with eyes open and focused on a head-synchronized target.

Numbers in brackets are number of subjects

A = all subjects
N = subjects not susceptible to S.M.S.
S = subjects susceptible to S.M.S.

Description of data reduction is given in the report.

Table I-1.— STS 4-6 Head Oscillation Frequency Summary, Hz Mean and S.D.

		VVOR EO	VOR EC	VOR ES	$\overline{X}$
Preflight					
n=5	N	0.29 ± 0.02	0.28 ± 0.03	0.33 ± 0.02[3]	29.3
n=3	S	0.27 ± 0.02	0.24 ± 0.01	0.25 ± 0.02[1]	25.3
n=8	A	0.28 ± 0.01	0.27 ± 0.02	0.31 ± 0.02[4]	28.6
Inflight 1					
n=5	N	0.27 ± 0.02	0.27 ± 0.02[4]	0.29 ± 0.01[3]	27.6
n=3	S	—		—	—
n=8	A	0.27 ± 0.02	0.27 ± 0.02[4]	0.29 ± 0.01[3]	27.6
Inflight 2					
n=5	N	0.23 ± 0.01	0.27 ± 0.02	0.24 ± 0.01[2]	24.6
n=3	S	0.29 ± 0.02	0.27 ± 0.01	0.27 ± 0.01[1]	27.6
n=8	A	0.26 ± 0.02	0.27 ± 0.01	0.25 ± 0.01[3]	26.0
Inflight 3					
n=5	N	0.27 ± 0.01	0.23 ± 0.01	0.28 ± 0.01[3]	26.0
n=3	S	0.26 ± 0.01	0.24 ± 0.05	0.24 ± 0.02[1]	24.6
n=8	A	0.27 ± 0.01	0.24 ± 0.01	0.27 ± 0.01[4]	25.6
Postflight					
n=5	N	0.29 ± 0.01[4]	0.28 ± 0.01[4]	—	28.5
n=3	S	0.33 ± 0.02[1]	0.31 ± 0.02[1]	—	32.0
n=8	A	0.30 ± 0.01[5]	0.28 ± 0.01[5]	—	29.0

Table I-2.— STS-4 Head Oscillation Frequency Summary, Hz, Mean and S.D.

	CDR		PLT	
	EO	EC	EO	EC
Preflight (F-16)	0.44 ± 0.02	0.41 ± 0.04	0.34 ± 0.02	0.25
00:14:00	0.33 ± 0.04	0.32 ± 0.03	—	—
~02:06:00	0.25 ± 0.03	0.38 ± 0.06	0.33 ± 0.03	0.30
~04:00:00	0.21	0.20	0.36	0.32

Table I-3A.— STS-5 Preflight Head Oscillation Frequency Summary, Hz, Mean and S.D.

	Frequency	
	EO	EC
MS1		
10/14/82	0.30 ± 0.01	0.31 ± 0.01
10/28/82	0.30	0.23
MS2		
10/7/82	0.19 ± 0.01	0.21
10/14/82	0.25 ± 0.03	0.23 ± 0.01
10/28/82	0.23 ± 0.02	0.22 ± 0.01

Table I-3B.— STS-5 Head Oscillation Frequency Summary, Hz, Mean and S.D.

	MS1	MS2	$\bar{X}$
Frequency - EO			
Preflight	0.30 ± 0.01	0.22 ± 0.03	0.26
Launch 1	0.20	—	
Launch 2	0.25 ± 0.02	—	
On Orbit 1	0.20	0.25	0.23
On Orbit 2	0.23	0.27	0.25
Entry 1	—	0.40 ± 0.23	
Entry 2	—	0.30 ± 0.02	
Entry 3	—	0.38 ± 0.04	
Postflight 1	0.27 ± 0.03	0.33 ± 0.02	0.30
Postflight 2	0.33 ± 0.01	0.27 ± 0.03	0.30
Frequency - EC			
Preflight	0.27	0.22 ± 0.01	0.25
Launch 1	0.19	—	
Launch 2	0.22	—	
On Orbit 1	0.16	0.19	0.18
On Orbit 2	0.16	0.25	0.21
Entry 1	—	0.39 ± 0.02	
Entry 2	—	0.34 ± 0.02	
Entry 3	—	0.39 ± 0.03	
Postflight 1	0.24 ± 0.01	0.31 ± 0.02	0.28
Postflight 2	0.35 ± 0.01	0.28 ± 0.02	0.32

Table I-4A.— STS-6 Preflight Head Oscillation Frequency Summary, Hz, Mean and S.D.

	EO	EC	ES
CDR			
1/24/83	0.22 ± 0.02	0.23 ± 0.01	—
2/16/83	0.25 ± 0.01	0.25 ± 0.01	0.29 ± 0.02
$\bar{X}$	0.24	0.24	0.29
PLT			
1/25/83	0.27 ± 0.03	0.27 ± 0.00	—
3/21/83	0.21 ± 0.02	0.23 ± 0.01	0.25 ± 0.02
$\bar{X}$	0.24	0.25	0.25
MS1			
2/16/83	0.20 ± 0.02	0.21 ± 0.01	0.31 ± 0.02
MS2			
2/11/83 #1	0.22 ± 0.02	0.23 ± 0.01	—
2/11/83 #2	0.24 ± 0.01	0.24 ± 0.02	—
2/16/83	0.37 ± 0.03	0.37 ± 0.01	0.39 ± 0.04
$\bar{X}$	0.28	0.28 ± 0.08	0.39

Table I-4B.— STS-6 Head Oscillation Frequency Summary, Hz, Mean and S.D.

	Preflight	MD1	MD2	MD4	Postflight
Frequency - EO					
CDR	0.24	0.22	0.21 ± 0.02	0.26 ± 0.02	0.25 ± 0.01
PLT	0.24	—	0.30 ± 0.03	0.14 ± 0.01	—
MS1	0.20 ± 0.02	0.20 ± 0.03	0.19 ± 0.02	0.25 ± 0.02	0.22 ± 0.01
MS2	0.28 ± 0.08	0.39 ± 0.04	0.31 ± 0.02	0.41 ± 0.02	0.43 ± 0.02
$\overline{X}$ ± S.D.	0.24 ± 0.03	0.27 ± 0.02	0.25 ± 0.05	0.27 ± 0.09	0.30 ± 0.09*
Frequency - EC					
CDR	0.24	—	0.23 ± 0.01	0.25 ± 0.01	0.24 ± 0.00
PLT	0.25	—	0.31 ± 0.01	0.15	—
MS1	0.21	0.19	0.23 ± 0.02	0.21	0.21 ± 0.01
MS2	0.28 ± 0.08	0.34 ± 0.02	0.35 ± 0.02	0.34 ± 0.01	0.42 ± 0.02
$\overline{X}$ ± S.D.	0.25 ± 0.03	0.27	0.28 ± 0.05	0.24 ± 0.07	0.29 ± 0.09*
Frequency - ES					
CDR	0.29 ± 0.02	0.19	0.25 ± 0.00	0.21 ± 0.02	—
PLT	0.25 ± 0.02	—	0.27 ± 0.01	0.24 ± 0.02	—
MS1	0.31 ± 0.02	0.29 ± 0.02	0.23 ± 0.02	0.24 ± 0.01	—
MS2	0.39 ± 0.04	0.40 ± 0.02	—	0.40 ± 0.02	—
$\overline{X}$ ± S.D.	0.31 ± 0.06	0.29 ± 0.01	0.25 ± 0.02*	0.27 ± 0.07	—

* n=3

Table I-5.— STS-4 Eye Amplitude Summary (EO only), Degrees Peak-to-Peak, Mean and S.D.

	CDR	PLT
Preflight	88.7 ± 7.2	74.0 ± 2.5
Inflight 1	70.5 ± 10.5	—
Inflight 2	78.8 ± 5.7	68.4 ± 4.2
Inflight 3	89.5 ± 4.3	68.9 ± 6.5

Table I-6.— STS-5 Eye Amplitude Summary (EO only), Degrees Peak-to-Peak, Mean and S.D.

		MS1	MS2
Preflight 1		—	92.4 ± 4.7
Preflight 2		76.7 ± 1.8	79.4 ± 2.4
Preflight 3		—	104.6 ± 7.0
$\bar{X}$		76.7 ± 1.8	92.1 ± 12.6
Launch 1		79.3 ± 6.8	—
Launch 2		82.0 ± 4.5	—
Orbit 1		85.0 ± 5.8	74.7 ± 2.1
Orbit 2		90.9 ± 5.3	69.8 ± 9.1
Entry 1		—	102.6 ± 4.8
Entry 2		—	81.2 ± 5.6
Entry 3		—	95.1 ± 7.0
Postflight 1		58.2 ± 3.5	79.7 ± 2.7
Postflight 2	#1	37.9 ± 3,2	69.0 ± 4.8
	#2	40.9 ± 5.5	
	#3	41.4 ± 3.6	
		40.1 ± 1.9	

Table I-7.— STS-6 Eye Amplitude Summary, Degreees Peak-to-Peak, Mean and S.D.

	CDR	PLT	MS1	MS2	$\overline{X}$
Preflight 1	55.3 ± 2.6	76.0 ± 3.7	—	—	65.7
Preflight 2	—	—	—	89.9 ± 2.6 44.7 ± 4.1	67.3
Preflight 3	72.4 ± 2.0	—	62.9 ± 7.0	52.9 ± 3.5	62.7
Preflight 4	—	79.1 ± 9.0	—	—	79.1
$\overline{X}$	63.9	77.6	62.9	62.5	66.7
Orbit 1	69.2 ± 9.9	—	71.7 ± 2.4	77.4 ± 6.1	72.8 ± 4.2
Orbit 2	61.4 ± 6.1	69.6 ± 6.4	64.1 ± 3.9	94.2 ± 3.7	72.3 ± 15.0
Orbit 3	57.5 ± 4.2	63.0 ± 3.7	58.1 ± 4.1	59.5 ± 2.7	59.5 ± 2.5
Postflight	75.0 ± 4.0	—	78.8 ± 3.5	78.1 ± 3.9	77.3 ± 2.0

Table I-8.— Number of Head Turns Susceptible (S) vs. Non-Susceptible (N)

	Pre	In_1	In_2	In_3	Post
EO - S	$4.4_{(3)}$	—	3.3	3.3	$4_{(1)}$
N	$4.5_{(5)}$	$2.9_{(5)}$	$3.4_{(5)}$	$2.8_{(5)}$	$3.5_{(4)}$
EC - S	$2.9_{(3)}$	—	$3.0_{(3)}$	$2.7_{(3)}$	$4.0_{(1)}$
N	$4.2_{(5)}$	$2.5_{(4)}$	$3.0_{(5)}$	$2.6_{(5)}$	$4.0_{(4)}$
ES - S	$5_{(1)}$	—	$3.0_{(1)}$	$3.0_{(1)}$	—
N	$6.7_{(3)}$	$3.0_{(3)}$	$4.5_{(2)}$	$3.7_{(3)}$	—
HT - S	$4.8_{(2)}$	—	$4.0_{(1)}$	$5.0_{(1)}$	$6.0_{(1)}$
N	$7.0_{(4)}$	—	$4.5_{(4)}$	$3.5_{(4)}$	$4.0_{(4)}$

Table I-9.— STS-5 Waveform Morphology and Asymmetry

Sample		Morphology	Asymmetry	
Preflight				
MS1	10/14/82	EO - sine, occasionally irregular, trapezoidal	33.3%	L>R
		EC - good sine, irregular, trapezoidal	62.6%	L>R
		HT - good sine, frequent, trapezoidal	8.8%	L>R
MS1	10/28/82	EO - fair sine, frequently irregular, trapezoidal	20.7%	R>L
		EC - poor sine, frequently irregular, trapezoidal	55.5%	L>R
		HT - triangular, occasionally trapezoidal	26.7%	L>R
MS2	10/7/82	EO - good sine, occasionally trapezoidal	18.7%	L>R
		EC - good sine, minimum trapezoidal	21.4%	R>L
		HT - poor head turns, pauses, one trapezoidal	—	—
MS2	10/14/82	EO - good sine, occasionally irregular, trapezoidal	36.7%	L>R
		EC - triangular with trapezoidal	15.0%	L>R
		HT - triangular with trapezoidal (esp (L))	68.3%	R>L
MS2	10/28/82	EO - alt sine/triangular, trapezoidal	19.3%	L>R
		EC - good sine with occasional trapezoidal	13.8%	R>L
		HT - alt sine/triangular with trapezoidal	36.1%	R>L
Inflight				
MS1	Launch 1	EO - good sine	71.4%	R>L
		EC - triangular	63.5%	R>L
MS1	Launch 2	EO - trapezoidal to poor sine	—	—
		EC - triangular with trapezoidal	—	—
MS1	Orbit 1	EO - good sine occasionally trapezoidal	16.7%	L>R
		EC - good sine	8.1%	L>R
		HT - good sine	31.9%	L>R
MS1	Orbit 2	EO - triangular with trapezoidal and irregular	21.7%	L>R
		EC - alt sine/triangular with trapezoidal	8.7%	L>R
		HT - fair sine, no trapezoidal	61.5%	R>L
MS2	Orbit 1	EO - very good sine	20.3%	L>R
		EC - good sine with trapezoidal	40.6%	R>L
MS2	Orbit 2	EO - good sine	21.7%	L>R
		EC - good sine, with occasional trapezoidal	40.0%	L>R
MS2	Entry 1	EO - sine/triangular	—	
		EC - sine/triangular	—	—
MS2	Entry 2	EO - good sine	8.1%	R>L
		EC - sine/triangular	10.2%	R>L
MS2	Entry 3	EO - triangular	5.4%	L>R
		EC - triangular	13.8%	L>R

Table I-9.— Continued

Sample		Morphology	Asymmetry	
Postflight				
MS1	Post 1	EO - good sine, occasionally irregular	12.5%	R>L
		EC - triangular, low amplitude	14.3%	R>L
MS1	Post 2 #1	EO - good sine	2.0%	R>L
		EC - good sine	3.9%	R>L
	#2	EO - fair to good sine	5.8%	R>L
		EC - good sine occasionally irregular	1.6%	R>L
		HT - fair sine to triangular	6.9%	L>R
	#3	EO - good sine	8.8%	R>L
		EC - good sine, occasionally irregular	4.3%	L>R
MS2	Post 1	EO - good sine, occasionally trapezoidal	30.0%	R>L
		EC - good sine	23.8%	R>L
		HT - sine to triangular	4.2%	L>R
MS2	Post 2	EO - good sine occasionally irregular	10.2%	L>R
		EC - good sine occasionally irregular	11.1%	L>R

Table I-10.— STS-6 Waveform Morphology and Asymmetry

Sample			Morphology	Asymmetry	
Preflight					
CDR	1/24/83		EO - sine, triangular	7.0%	R>L
			EC - good sine	8.1%	L>R
			HT - triangular	3.8%	L>R
CDR	2/16/83		EO - triangular	10.2%	L>R
			EC - triangular with trapezoidal throughout	15.1%	L>R
			HT - triangular with trapezoidal throughout	14.4%	R>L
			ES - triangular with trapezoidal throughout	26.5%	L>R
PLT	1/25/83		EO - triangular	14.1%	R>L
			EC - triangular to poor sine	16.9%	R>L
			HT - triangular	0%	=
PLT	3/21/83		EO - triangular and sine, occasionally trapezoidal	1.6%	R>L
			EC - triangular with trapezoidal	8.1%	L>R
			HT - triangular, frequently trapezoidal	13.8%	L>R
			ES - poor sine to triangular, occasionally trapezoidal	6.6%	R>L
MS1	2/16/83		EO - good sine, with trapezoidal	28.3%	L>R
			EC - sine, with trapezoidal	1.7%	L>R
			HT - good sine, with occasionally trapezoidal	2.1%	R>L
			ES - mostly sine, some triangular, occasionally trapezoidal	11.4%	L>R
MS2	2/11/83	#1	EO - triangular with trapezoidal	17.6%	R>L
			EC - triangular with trapezoidal	20.3%	R>L
			HT - triangular with trapezoidal	5.2%	R>L
		#2	EO - fair sine, with occasionally trapezoidal	15.5%	R>L
			EC - trapezoidal	28.6%	R>L
MS2	2/16/83		EO - sine with trapezoidal throughout	21.4%	R>L
			EC - trapezoidal	4.7%	R>L
			HT - trapezoidal	7.0%	R>L
			ES - poor sine, trapezoidal	6.6%	R>L
Inflight EOG #2					
CDR			EO - sine to triangular with some trapezoidal	15.5%	R>L
			EC - trapezoidal	10.6%	L>R
			HT - trapezoidal	0.5%	R>L
			ES - trapezoidal	7.0%	L>R
PLT			EO - sine and traingular, with occasionally trapezoidal	1.8%	R>L
			EC - sine and trapezoidal	5.5%	L>R
			HT - triangular and trapezoidal	6.5%	R>L
			ES - sine to triangular	3.2%	L>R
MS1			EO - good sine, with trapezoidal	11.1%	R>L
			EC - sine with trapezoidal	2.9%	R>L
			HT - sine with triangular	4.3%	R>L
			ES - sine with occasionally trapezoidal	5.0%	L>R
MS2			EO - triangular	2.0%	R>L
			EC - triangular and sine	10.6%	R>L
			HT - triangular	9.3%	R>L

Table I-10.— Continued

Sample	Morphology	Asymmetry	
Inflight EOG #3			
CDR	EO - triangular and trapezoidal	11.4%	R>L
	EC - triangular	1.9%	R>L
	HT - triangular with trapezoidal	8.6%	R>L
	ES - trapezoidal	11.0%	R>L
PLT	EO - good sine, with rare trapezoidal	1.3%	L>R
	EC - fair sine, with occasionally trapezoidal	19.3%	L>R
	HT - poor sine/triangular/trapezoidal	16.3%	L>L
	ES - fair sine with occasionally trapezoidal	11.8%	L>R
MS1	EO - triangular with occasionally trapezoidal	23.5%	R>L
	EC - triangular with trapezoidal	10.8%	R>L
	HT - trapezoidal	13.4%	R>L
	ES - sine-to-sine with trapezoidal	7.0%	R>L
MS2	EO - triangular with occasionally trapezoidal	0.7%	R>L
	EC - trapezoidal	11.7%	R>L
	HT - triangular	13.3%	R>L
	ES - triangular, with rare trapezoidal	10.2%	R>L
Postflight			
CDR	EO - triangular	0%	=
	EC - triangular	10.9%	R>L
	HT - triangular	2.5%	L>R
MS1	EO - sine	20.0%	R>L
	EC - sine	7.0%	R>L
	HT - sine	5.6%	R>L
MS2	EO - sine	13.5%	R>L
	EC - sine	16.9%	R>L
	HT - sine	21.3%	R>L

Table I-11A.— STS-5 VVOR and VOR Gain Preflight

	EO	EC	EC/EO	HT	
				n	Ampl
MS1					
10/14/82	0.75 ± 0.05	0.46 ± 0.12	0.61	22	3.6 ± 1.2
10/28/82	—	—	—	11	1.5 ± 0.4
$\overline{X}$	0.75 ± 0.05	0.46 ± 0.12	0.61	16.5	2.6
MS2					
10/7/82	1.02 ± 0.08	0.98 ± 0.09	0.96	4	3.1 ± 0.4
10/14/82	0.83 ± 0.07	0.64 ± 0.12	0.77	14	4.1 ± 1.1
10/28/82	0.67 ± 0.04	0.53 ± 0.09	0.79	13	5.6 ± 1.7
$\overline{X}$	0.84 ± 0.18	0.72 ± 0.23	0.84	10.3	4.3 ± 1.3

Data are not considered reliable because of head potentiometer coupling.

Table I-11B.— STS-5 VVOR and VOR Gain Summary

	MS1	MS2	$\bar{X}$
VOR Gain - EO			
Preflight	0.75 ± 0.05	0.84 ± 0.18	0.80
Launch 1	0.58 ± 0.04	—	
Launch 2	0.55 ± 0.06	—	
On Orbit 1	—	1.06 ± 0.07	
On Orbit 2	1.16 ± 0.06	1.10 ± 0.09	1.13
Entry 1	—	1.02 ± 0.07	
Entry 2	—	0.98 ± 0.03	
Entry 3	—	0.93 ± 0.04	
Postflight 1	1.11	1.11	1.11
Postflight 2	0.75	1.37	1.06
VOR Gain - EC			
Preflight	0.46 ± 0.12	0.72 ± 0.23	0.59
Launch 1	0.42	—	
Launch 2	0.25 ± 0.06	—	
On Orbit 1	0.98 ± 0.19	0.70 ± 0.09	0.84
On Orbit 2	1.26 ± 0.29	1.56 ± 0.07	1.41
Entry 1	—	0.38 ± 0.11	
Entry 2	—	0.28 ± 0.07	
Entry 3	—	0.31 ± 0.12	
Postflight 1	1.54	0.50	1.02
Postflight 2	0.47	0.91	0.69
EC/EO			
Preflight	0.61	0.84	0.74
Launch 1	0.72	—	
Launch 2	0.45	—	
On Orbit 1	0.48	0.66	0.54
On Orbit 2	1.09	1.42	1.25
Entry 1	—	0.37	
Entry 2	—	0.29	
Entry 3	—	0.33	
Postflight 1	1.39	0.45	0.92
Postflight 2	0.62	0.66	0.65

Table I-12A.— STS-6 Preflight Reflex Gain Summary

	VVOR EO	VOR EC	VOR ES	EC/EO	ES/EO
CDR					
1/24/83	0.95 ± 0.03	1.16 ± 0.07	—	1.22	—
2/16/83	0.97 ± 0.02	1.11 ± 0.06	0.60 ± 0.07	1.52	0.62
$\overline{X}$	0.96	1.14	0.60	1.37	0.62
PLT					
1/25/83 #1	1.14 ± 0.05	—	—	—	
1/25/83 #2	1.00 ± 0.04	0.89 ± 0.08	—	0.89	
3/21/83	1.00 ± 0.06	0.88 ± 0.11	0.82 ± 0.06	0.88	0.82
$\overline{X}$	1.05	0.89	0.82	0.89	0.82
MS1					
2/16/83	1.08 ± 0.07	0.81 ± 0.11	0.68 ± 0.06	0.75	0.63
MS2					
2/11/83 #1	1.04 ± 0.03	1.22 ± 0.08	—	1.17	
2/11/83 #2	0.94 ± 0.04	1.45 ± 0.17	—	1.54	
2/16/83	0.94 ± 0.03	1.43 ± 0.16	0.85 ± 0.05	1.52	0.90
$\overline{X}$	0.97 ± 0.06	1.37 ± 0.13	0.85	1.41	0.90

Table I-12B.— STS-6 EOG Data - Reflex Gain Summary

	Preflight	MD2	MD4	Postflight
VVOR Gain - EO				
CDR	0.96	1.08 ± 0.09	1.13 ± 0.70	1.09 ± 0.07
PLT	1.05 ± 0.08	1.00 ± 0.05	1.01 ± 0.10	—
MS1	1.08 ± 0.07	0.94 ± 0.04	1.07 ± 0.08	1.22 ± 0.06
MS2	0.97 ± 0.06	1.16 ± 0.03	0.87 ± 0.04	1.02 ± 0.07
$\bar{X}$	1.02 ± 0.06	1.05 ± 0.10	1.02 ± 0.11	1.11 ± 0.10*
VOR Gain - EC				
CDR	1.14	1.39 ± 0.11	1.03 ± 0.05	1.19 ± 0.06
PLT	0.89	0.97 ± 0.09	0.61 ± 0.06	—
MS1	0.81 ± 0.11	0.32 ± 0.12	0.96 ± 0.05	0.59 ± 0.16
MS2	1.37 ± 0.13	1.39 ± 0.05	1.26 ± 0.04	1.73 ± 0.10
$\bar{X}$	1.05 ± 0.25	1.02 ± 0.51	0.97 ± 0.27	1.17 ± 0.57*
VOR Gain - ES				
CDR	0.60 ± 0.07	0.77 ± 0.07	1.05 ± 0.10	—
PLT	0.82	0.87 ± 0.05	0.78	-
MS1	0.68 ± 0.06	0.59	0.80	-
MS2	0.85 ± 0.05	—	0.82 ± 0.10	—
$\bar{X}$	0.74 ± 0.12	0.74 ± 0.14*	0.86 ± 0.13	
$\bar{X}$ ES/EO	0.73	0.71	0.84	—
$\bar{X}$ EC/EO	1.05	0.95	0.97	1.08

*n=3

Table I-13.— STS-5 Phase Shift Summary, Degrees

	MS1	MS2	$\bar{X}$
Phase Shift - EO			
Preflight	29.8 ± 4.9	41.4 ± 1.9	35.6
Launch 1	23.3 ± 9.0	—	
Launch 2	34.8 ± 13.0	—	
On Orbit 1	35.0 ± 4.4	27.3 ± 0.9	31.2
On Orbit 2	21.1 ± 5.2	49.5	35.3
Entry 1	—	14.5 ± 1.8	—
Entry 2	—	34.5 ± 14.4	
Entry 3	—	16.4 ± 2.8	
Postflight 1	37.3 ± 6.7	35.5 ± 10.0	36.4
Postflight 2	21.0 ± 3.6	18.2 ± 7.9	19.6
Phase Shift - EC			
Preflight	29.0 ± 6.8	29.4 ± 7.1	29.2
Launch 1	29.8	—	
Launch 2	19.4 ± 2.0	—	
On Orbit 1	43.0 ± 5.6	27.5 ± 2.8	35.3
On Orbit 2	19.4 ± 9.2	38.4 ± 17.9	28.9
Entry 1	—	17.0 ± 5.1	
Entry 2	—	26.7 ± 8.4	
Entry 3	—	14.3 ± 6.9	
Postflight 1	30.2 ± 6.8	33.5 ± 7.0	31.9
Postflight 2	24.9 ± 1.8	10.3 ± 11.7	17.6

Table I-14A.— STS-6 Preflight Phase Shift Summary, Degrees

	EO	EC	ES
CDR			
1/24/83	21.3 ± 6.6	27.8 ± 7.3	—
2/16/83	17.3 ± 5.3	26.2 ± 3.8	28.8 ± 7.4
•$\overline{X}$	19.3	27.0	28.8
PLT			
1/25/83	33.9 ± 7.5	30.4 ± 8.2	—
3/21/83	30.0 ± 7.4	35.3 ± 10.7	34.1 ± 15.1
$\overline{X}$	32.0	32.9	34.1
MS1			
2/16/83	32.3 ± 7.8	27.8 ± 6.6	16.6 ± 18.8
MS2			
2/11/83 #1	24.7 ± 8.8	25.0 ± 5.3	—
2/11/83 #2	25.4 ± 6.8	32.4 ± 4.3	—
2/16/83	37.3 ± 4.6	33.0 ± 10.3	34.6 ± 8.0
$\overline{X}$	29.1	30.1 ± 4.5	34.6

Table I-14B.— STS-6 Phase Shift Summary, Degrees

	Preflight	MD2	MD4	Postflight
Phase Shift - EO				
CDR	19.3	22.7 ± 5.4	14.0 ± 4.1	16.8 ± 2.4
PLT	32.0	22.7 ± 3.6	35.4 ± 7.1	—
MS1	32.9 ± 7.8	32.8 ± 16.6	25.4 ± 9.0	18.9 ± 4.9
MS2	29.1	20.7 ± 5.6	15.4 ± 1.4	21.2 ± 8.1
$\overline{X}$ ± S.D.	28.3 ± 5.4	24.7 ± 4.7	22.6 ± 8.6	19.0 ± 1.8*
Phase Shift - EC				
CDR	27.0	30.1 ± 9.1	8.5 ± 6.0	20.5 ± 5.8
PLT	32.9	41.3 ± 6.0	6.7 ± 7.5	—
MS1	27.8 ± 6.6	15.8 ± 5.8	25.5 ± 5.0	8.9 ± 7.0
MS2	30.1 ± 4.5	16.6 ± 3.8	24.8 ± 4.2	29.0 ± 14.4
$\overline{X}$ ± S.D.	29.5 ± 2.6	26.0 ± 10.5	16.4 ± 8.8	19.5 ± 8.2*
Phase Shift - ES				
CDR	28.8 ± 7.4	3.9 ± 15.6	6.2 ± 11.6	—
PLT	34.1 ± 15.1	16.4 ± 6.1	—	—
MS1	16.6 ± 18.8	3.8 ± 18.2	9.3 ± 9.8	—
MS2	34.6 ± 8.0	—	14.8 ± 7.3	—
$\overline{X}$ ± S.D.	28.5 ± 8.4	8.0 ± 5.9*	6.0 ± 10.9*	—

*n=3

APPENDIX II — HARDWARE

Table II-1.— Low Frequency Gain and Phase Characteristics of EOG Amplifiers

Frequency	SN 124			SN 126			SN 127		
	EO (V P-P)	Gain	Phase	EO (V P-P)	Gain	Phase	EO (V P-P)	Gain	Phase
0.05	3.55	355	44.4°	3.52	352	44.9°	3.61	361	44.4°
0.1	4.41	441	27.8°	4.36	436	27.5°	4.46	446	27.5°
0.2	4.83	483	14.7°	4.74	474	14.1°	4.85	485	15.0°
0.3	4.93	493	9.7°	4.87	487	9.4°	4.94	494	10.0°
0.4	5.00	500	7.6°	4.89	489	6.4°	4.94	494	7.4°
0.5	5.00	500	5.9°	4.895	489.5	4.9°	4.95	495	5.8°
1.0	5.00	500	3.2°	4.911	491.1	2.7°	5.03	503	2.7°
3.0	5.00	500	0°	4.911	491.1	0°	5.03	503	0°
5.0	5.00	500	3.9°	4.911	491.1	2.4°	4.933	493.3	2.7°

Note: Gain preset at 500 at 5 Hz
E_{IN} = 10 MV P-P/Constant

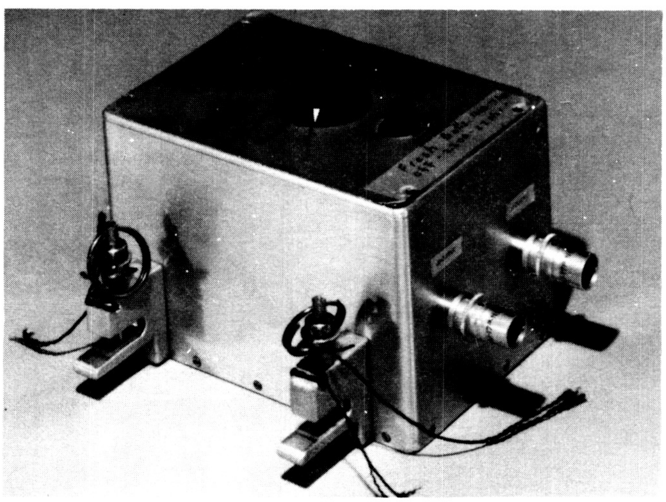

Fig. II-1.— Control box for STS-5. Various testing modes were activated by position of rotary switch. All electronics and battery power were contained in this unit.

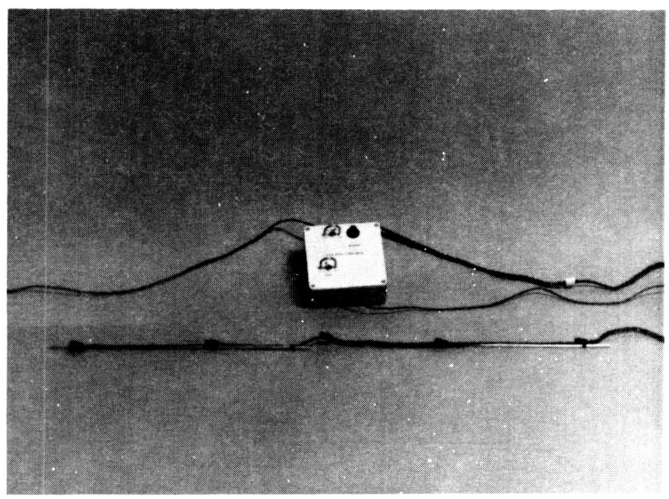

Fig. II-2.— Control box and target light assemblies for STS-6.

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16. Abstract

The vestibulo-ocular reflex (VOR) may be altered by weightlessness. Since this reflex plays a large role in visual stabilization, it was important to document any changes caused by space flight. This is a report of findings on STS-4 through 6 and is a part of a larger study of neurosensory adaptation done on STS-4 through 8. Voluntary horizontal head oscillations at 1 3 Hz with amplitude of 30° right and left of center were recorded by a potentiometer and compared to eye position recorded by electroculography under the following conditions: eyes open, head fixed, tracking horizontal targets switched 0°, 15° and 30° right and left (optokinetic reflex [OKR] and calibration); eyes open and fixed on static external target with head oscillation (visual vestibulo-ocular reflex (VVOR)); eyes closed but fixed in imagination on previous target with head oscillation, (vestibulo-ocular reflex, eyes closed (VOR EC)); eyes open and wearing opaque goggles with target fixed in imagination (vestibulo-ocular reflex, eyes shaded (VOR ES)); and eyes open and fixed on a head synchronized target with head oscillation (VOR suppression). No significant changes were found in voluntary head oscillation frequency or amplitude in those with (n=5), and without (n=3), space motion sickness (SMS), with phase of flight or test condition. Variations in head oscillation were too small to have produced detectable changes in test results. Four subjects with adequate data showed no significant change in VVOR gain/phase, VOR EC gain/phase or VOR suppression. There was a small but significant increase in VOR ES on MD-4 and similar increase in phase shift (eyes lead head) on MD-2 and 4 during VOR ES. There was no evidence for any change of clinical or operational significance. The validity of the above findings will be further tested when similar data from STS-7 and 8 (n=10) are available.

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